Experimental Determination of Capacity of Pile Group and Pile Raft Foundation

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Abstract

Pile raft foundation is at type of foundation that can be used to support heavier structures over a soil of moderate to low bearing capacity through its complex soil-structure interaction. Researchers have carried out numerical studies on the analysis and design of pile raft foundation and pile group and it is proved that pile group and pile raft foundation have difference in load carrying capacities. R. Katzenbach et. al (2005) said that the raft in pile raft foundation increases the stress between the soil and piles and hence contributes to the load capacity of piles in comparison to pile group when piles are free standing. This paper basically provides an experimental verification of their behavior. This paper is aimed to calculate the settlement behaviors of pile group and pile raft foundation experimentally. For this small-scale model is prepared for experimentation, where pile is made up of copper and raft is of aluminum. Experimental model is placed in a soil box and vertical loading is applied through a hydraulic straining frame at a very slow rate. It is found that load carrying capacity of the pile raft is much greater than that of the pile group and vertical settlement is also reduced substantially in case of pile raft foundation.

Keywords: pile group and pile raft foundation, small scale model, settlement

1. INTRODUCTION

Foundation is an element of the structure that transfer the load of superstructure deep in to the ground to that layer which has the required strength. Main purpose of foundation is to bear the load of super structure, to stabilize it against natural forces (earthquake, wind etc.) and to protect it from ground moisture. Shallow foundation is provided when the soil underneath is stiff and has the required bearing capacity to transfer the load in shallow depth while deep foundation is provided where the soil is soft and/or there is a high-rise structure which is more expose to wind and earthquake loads. Pile raft and pile group foundation are types of deep foundation which transfer load by bearing and shearing. In pile raft foundation, raft has a direct contact with soil while pile group foundation has no such a contact between raft and soil underneath. In pile raft foundation load is transferred through the complex soil structure interaction which occurs among piles, raft and soil while pile group is not having such a complex load transfer mechanism. In pile raft foundation, raft control the differential settlement and piles reduce the settlement and stresses in the soil. In pile group foundation as raft has no contact with soil below it and hence doesn't transfer any load while in case of pile raft foundation raft must be in direct contact with the soil underneath and hence load is transferred through piles as well as raft. The load transfer mechanism of pile raft foundation is complex and has no exact solution except the finite element analysis. However some researchers have proposed simplified methods of analysis which are presented below.

I. Poulos and Davis method

This describes the load-displacement behavior of piled raft foundation as a tri-linear curve shown in fig.1. The curve has three regions, in the first region both piles and raft resist the load, in the second region pile capacity is fully mobilized thereby exerting extra demand on raft, while in the third region pile plus raft ultimate capacity is utilized.

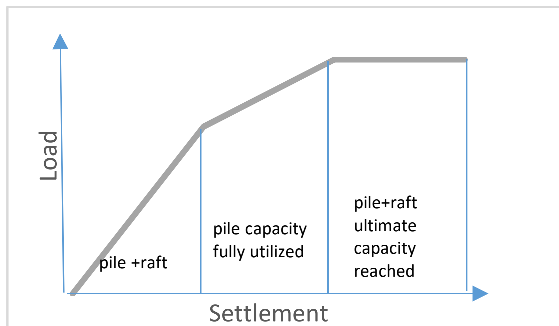

fig.1 Idealized load settlement behavior (Poulos)

II. Randolph method

This method incorporated stiffness of piles, raft and also the interaction between the piles and raft to give a formula for combined stiffness of piles and raft (K_{pr}) as shown below.

$$K_{pr} = \frac{K_p + (1-2\alpha_{rp})K_r}{1-\alpha_{rp}^2 (K_r/K_p)} \qquad \alpha_{rp} \cong 1 - \frac{\ln(r_c/r_o)}{\zeta}$$

Where K_p and K_r are the respective stiffness's of the piles and the raft. α_{rp} is the interaction between the piles and the raft.

The load distribution between the piles and raft given by this method as follows:

$$\frac{P_r}{P_r + P_p} = \frac{(1-\alpha_{rp})K_r}{K_p + (1-2\alpha_{rp})K_r}$$

The method also provided a relation to determine the vertical displacement of piled raft foundation (S) as follows:

$S = \frac{P}{K_{pr}}$ where P is applied load on the system.

III. Poulos-Davis-Randolph method

This method has combined the Poulos-Davis and Randolph in such a way that later is used for determining the load distribution among the piles and raft and former is employed to see the load settlement behavior of system. The load P_l at which pile capacity is fully mobilized is:

$P_l = \frac{P_{up}}{1-X}$ where P_{up} is the ultimate load capacity of pile group and X is load ratio of P_r to P_p.

In case the load applied is only up to P_l, the settlement of the system is: $S = \frac{P}{K_{pr}}$

For load beyond P_l, $S = \frac{P}{K_{pr}} + \frac{P-P_l}{K_r}$

2. EXPERIMENTAL BACKGROUND OF PILE RAFT AND PILE GROUP

Various researchers have conducted experiments to assess the pile group and pile raft foundations. Katzenbach, R., & Moormann, C. (1998) also monitored the experimental model of piled raft foundation and instrumented the model. The testing included the comparison of load settlement behavior of a single pile, single pile with raft and 25 piles with raft as a piled raft foundation while studying the influence of pile-pile and pile raft interaction. The experimental testing showed that only a small part of the load is transferred to soil by the raft, while the load distribution among the piles is such that pile load decreases from the corner piles to the edge piles and reduces significantly to the inner piles. Similarly, M. H. Baziar et. Al (2009) also conducted experimental testing on a small scale 1g physical model that consisted of circular raft and four piles, along with numerical simulation in FLAC-3D and PDR method to study the bearing settlement behavior of piled raft foundation on medium dense sand. The results of these methods adopted were compared and it showed that PDR method works well as long as load applied is in linear range. Beren Yilmaz (2010) conducted laboratory testing on small scale pile raft models with different number of piles. The experimental model included brass nails, aluminum piles, soil box and a soil. Loading jack, loading hangers, displacement dial gauges and data logger were the equipment. A total of 16 soil boxes were prepared and testing was conducted on a single raft, pile raft of 16 piles and raft with 49 piles. Along with this analytical and a numerical method was also employed. It has been concluded that an optimum number of piles are required to control the settlements and above those number of piles, settlement doesn't decrease and these loads is shared to the soil by both piles and raft.

Instrumentation is a term for measuring instruments which are used to measure, record and indicate physical quantities e.g. load, stress, strain, pressure, distance, settlement etc. In civil engineering practices stress and strain are commonly measured physical quantities in super structure through instrumentation while settlement measurement is preferred in sub structure. The most common instruments used by civil engineers are strain gauges, settlement transducer, load cells, pressure cells and many more. The type of instrument used depends on the type of quantity to be measured. Data from these instruments are recorded by multichannel data logger with which different instruments are connected through its channel and the data logger is connected to a computer programmed to store the data. Specific values of measuring factor are inserted in computer to exactly measure the physical quantity through instrument. In this paper experimental study of pile group and pile raft foundation is carried out in which settlement is important physical quantity to be measured, settlement transducer of 50 mm capacity and load cell are used to be measured the settlement produced in the model and the applied load respectively. UCAM 70 datalogger is used to record the data from the LVDTs and load cell.

3. METHODOLOGY

This research basically presents the comparison of the piled raft foundation and pile group foundation on the basis of their load settlement behavior through experimental testing program. The experimental testing was conducted in Materials Testing laboratory of Civil Engineering department of University of Engineering and Technology, Peshawar. Along with other equipment, lab is equipped with a Hydraulic Straining Frame having a capacity of 200KN.

For this research copper rods (length:2ft, diameter: 0.75inches) are used as pile, aluminum plate (square: 1ft x 1ft, thickness: 0.0196ft) as raft, a soil box (square:3.5ft x 3.5ft, hight:3ft) to carry soil, clayey plus sandy soil, load cell having a capacity of 5tons, linear vertical displacement transducers (LVDTs) of range 50mm and data acquisition system i.e. UCAM 70 data logger having 30 channels is used. Copper is selected as pile because it has sufficient elastic modulus to prevent axil strain in it so that the vertical settlement measured is only the due to injection of pile into soil. Aluminum plate is selected as raft because it bends uniformly when loaded and hence simulates the raft behavior in a good sense.

First an experimental setup is made to represent pile group foundation as shown in fig.2, and then setup for piled raft as shown in fig.3 is also made and the basic difference between the two is that soil is in contact with raft for piled raft foundation and for pile group foundation there is no such a contact. After this setup two LVDTs, one load cells and data logger UCAM 70 is connected to the setup as shown in figures below. Then load is applied to the experimental model and the load settlement data is recorded through UCAM 70. Load is vertically applied at the center of the model through the hydraulic straining frame. The rate of increase of vertical load is very low can be assumed as static load. Vertical load is applied to the model until the vertical settlement is measurable through LVDTs i.e. till 50mm but it is also decided that if excessive bending in raft occurs, loading should be stopped to prevent damage to the material. Therefore, for pile raft foundation loading is stopped at a settlement level of 35-40mm but for pile group foundation load is applied till a settlement of 50mm as there is no such a damage to raft being observed.

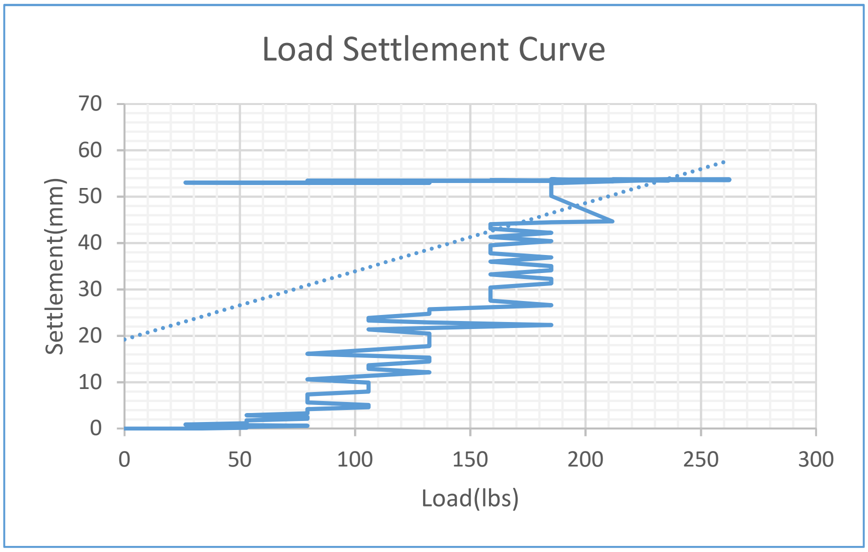

Figure 4: load settlement curve of pile group foundation

4. RESULTS AND DISCUSSION:

After the application of continuously increasing load on the pile group and pile raft foundation model separately, load and settlement values for both foundation type are obtained and graph between them is plotted.

Figure 2: Experimental setup for pile group model

Figure 3: Experimental setup for piled raft model

Figure 4 shows the settlement behavior of pile group foundation model in response to the continuously increasing vertical load. It can be seen from the graph that settlement of pile group increases with the increase in load on the model and at small values of load the settlement produce in the pile group model is greater. This is because only piles are transferring load to soil with zero contribution of raft because of no contact between soil and raft. The maximum load sustained by the pile group model is 200lb having settlement of 50mm. This capacity is very low and it is just because of the end bearing resistance of the piles with negligible shaft resistance. Shaft resistance is negligible because copper piles has less friction resistance to the sandy soil as compared to end bearing resistance.

Figure 5 shows the settlement behavior of pile raft foundation model under continuously increasing vertical load. It can be clearly seen that increasing the load increases the settlement of the pile raft foundation model but the settlement in this case is smaller at greater load values as compared to the pile group foundation. The graph of pile raft foundation model has two region, steep slope region corresponds to the load carried by both piles and raft while after the steep slope is a flat slope which shows that the capacity of the piles is fully mobilized and all the load is carried by the raft only. This behavior of pile raft (Fig.5) is in well agreement with Poulos as shown in Fig.1

Figure 4 seems to have graph with zigzag pattern but we should focus on the general trend as shown by the trend line of the graph. One of the reasons for that zigzag is at the start of the test soil starts readjusting itself until it gets stable by the soil and pile interaction. In the case of pile raft foundation as shown in figure 5 there is no such a zigzag because the soil adjusts itself quickly during the test because of soil-raft-pile interaction.

5. CONCLUSION:

After comparison of load settlement graph of pile group and pile raft foundation model it is concluded that behavior of both the graphs towards the applied load is same but the load carried by pile raft foundation model is greater than that of load carried by pile group which shows

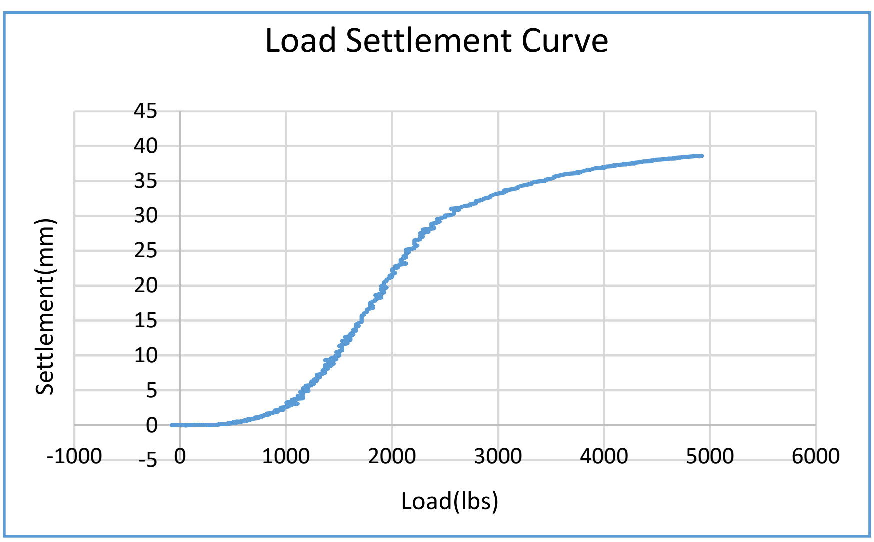

Figure 5: load settlement curve of pile raft foundation

that pile raft foundation has greater load carrying capacity than pile group foundation. The superiority of pile raft foundation is due to raft-soil and pile-raft interaction which doesn't exists in pile group.

It is also concluded that pile raft model is more efficient than pile group model for settlement reduction. Also, as both the foundations have raft but its capacity is only utilized in pile raft foundation, therefore, pile raft foundation is called as an economical alternative to deep foundation. So foundation engineer would prefer pile raft over pile group foundation.

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